Clutter characterization and propagation measurements during adverse weather conditions

by

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Abstract—**The evaluation of sensor performance under adverse weather conditions is critical for the determination of usability during all weather conditions. The Precisions Armaments Laboratory (PAL) located at the US Army Picatinny Arsenal, New Jersey, USA development will enable automated measurement of propagation effects and clutter characterization under adverse conditions.**

I. INTRODUCTION

Radar detection and discrimination is dependent not only on the target but also on the clutter in the range-azimuth resolution cell. The radar cross section (RCS) of clutter as well as its spectral content will be affected by meteorological conditions such as wind speed, direction, rain, snow, and ice. Propagation will also be affected by adverse weather condition. The US Army's Armament Research, Development and Engineering Center has constructed a Precision Armaments Laboratory (PAL) at Picatinny Arsenal, New Jersey, USA, specifically dedicated to the automated experimentation and evaluation of sensors under adverse weather conditions. The laboratory consists of a base building and a 61 m tower with two external elevators capable of serving as test beds for the radars, electro-optic, or other sensors under test and associated instrumentation (shown in Fig. 1). The tower overlooks three instrumented target site areas as well as a mid-range meteorological instrumentation site. Picatinny Arsenal's northern New Jersey location offers a wide and diverse variety of meteorological conditions. The Georgia Institute of Technology has been assisting Picatinny Arsenal with the development of the instrumentation for the laboratory, and the planning and conduct of the testing. Planned instrumentation of the PAL will not only enable measurement of propagation effects, but also measurement of clutter characteristics under adverse weather conditions.

II. RADAR AND TARGET SITE CONSIDERATIONS

The target and the radar need to be situated in a configuration that approximates that which will be encountered during normal operation of the radar. Normally, the target will be situated in a clutter background, and the radar returns from the target will be affected by the target aspect angle as well as the radar's elevation incident angle upon the target. In order to simulate the elevation incident angle, the radar sensor will have to be located on a tower to provide the elevation aspect angles. A further consideration is whether the target is in the near field or far field of the radar. MMW radars, for example, generally operate in the far field of the antenna, but are in the near field when considering the dimensions of the target and the critical "end-game" ranges as a precision munition tracks to target impact. The PAL facility, as shown in the plan view of Fig. 2, provides for three target ranges at 46m, 549m, and 1280m distances from the tower. The effective height of the PAL tower is 122m as it was specifically positioned atop a 61m ridge.

Fig. 1. PAL measurements tower.

Report Documentation Page

Form Approved
OMB No. 0704-0188

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1. REPORT DATE **14 APR 2005**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **Clutter characterization and propagation measurements during adverse weather conditions**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Georgia Tech Research Institute USA**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM001798, Proceedings of the International Conference on Radar (RADAR 2003) Held in Adelaide, Australia on 3-5 September 2003., The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**UU**	**5**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

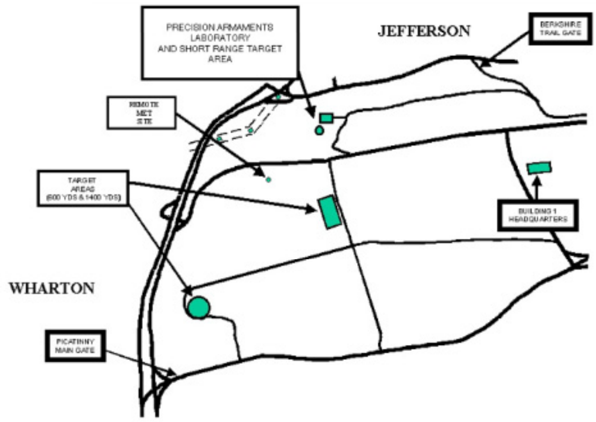

Fig. 2. Plan view of PAL measurement facility.

The orientation permits panoramic access to a vast portion of Picatinny Arsenal. Accordingly, longer ranges (up to 5.85 km) can be accommodated if required.

A. Operational Considerations

Collecting sensor/seeker performance data during adverse weather conditions has proven to be difficult at best. Obviously adverse weather conditions cannot be planned for and posturing test sites and crews at remote locations to collect such data proves to be very costly with the risk of not acquiring data at all. Furthermore, flight safety restrictions prevent fixed and rotary wing aircraft test platforms from collecting measurements during adverse weather.

The PAL addresses these test deficiencies through automation. The facility was planned and designed to provide customers a number of mounting platform options and automated control of the unit under test (UUT). In addition to static platforms, for certain munitions systems, automated dynamic descent/ascent measurements can be performed from the laboratory elevators. Adverse weather data collection requirements will be preprogrammed into the test control computer. UUT and meteorological measurements are automatically collected when the predefined conditions occur. Multiple customers can be served simultaneously, and due to the nature of weather dependent measurements, provisions will be made for extended data collection periods.

B. Clutter Characterization

Measurement of clutter characteristics requires measurement of the RCS for the clutter patch of interest. The mid and far range target sites and the mid-range instrumentation site are set in a valley that is approximately 122m below the top of the tower. Each of the target sites include meteorological instrumentation to determine the weather conditions exiting at the sites. The meteorological information is transmitted back to the base building, adjacent to the 61m tower, via fiber-optic cables for recording and automated test conduct initiation.

The view from the tower looking towards the target sites, shown in picture of Fig. 3 shows a wide variety of field and treeline situations that could be used for clutter characterization.

Facilitation plans call for implementing an RCS characterization radar at the PAL facility. Target and clutter characterization can be performed by the radar system pictured in Fig. 4. Planned acquisition of an Aeroflex Lintek radar system will enable full characterization of clutter phenomena. The radar is a highly capable commercially available measurement system specifically designed for coherent, dual polarized radar RCS measurements. It has the capability of supporting measurements over a wide range of frequencies, from 100 MHz up through 95 GHz, by using it with the appropriate RF heads. The diagram shows the radar along with the associated preamplifier and RF head. The radar has the capability of performing full polarization matrix measurements, in that it can switch transmit frequencies on a pulse-to- pulse basis, and has dual polarized receivers. The frequency of the radar can be changed on a pulse-to- pulse basis, and the received pulses can be coherently integrated over a large number of pulses. As such, the coherent integration capabilities enable the utilization of low power solid-state amplifiers for the transmitter source. The preamplifier provides the up-conversion of the transmit pulse to Ka-band or W-band frequencies, and provides the down frequency conversion for the dual polarization receiver signals.

Fig. 3. View from the PAL tower towards the target sites.

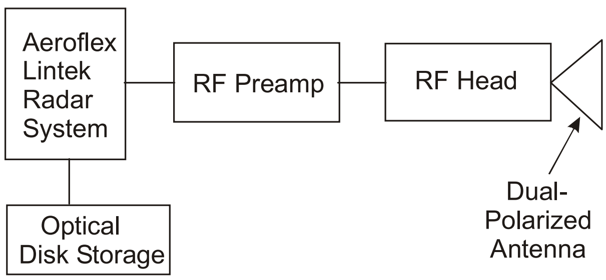

Fig. 4. RCS characterization radar block diagram.

The RF head provides the amplification of the transmit signal and couples it to the dual polarized antenna for transmit. The RF head is shown in the diagram of Fig. 5. The transmitter input (Tx) from the preamplifier is amplified and coupled to the RF switch and circulators to the dual polarized antenna. The RF switch determines the transmit polarization. The receive signal from the dual polarized antenna ports are coupled through the circulators to low noise amplifiers, and then to the receiver inputs of the preamplifier.

The size and complexity of the RF head can be considerably reduced if a solid-state amplifier can be used as the transmitter source. The power requirements can be determined by computing the received signal to noise using the radar range equation. The output signal to noise is also a function of the number of pulses coherently integrated and the gain of the dual polarized antenna.

C. Propagation Measurements

Attenuation due to adverse weather conditions along the RF propagation path can adversely affect radar detection and discrimination performance. Propagation path measurements at microwave and millimeter wave frequencies can be performed either by utilizing a radar, such as shown in Fig. 4, or by utilizing a microwave or millimeter wave transmissometer.

By utilizing radar, such as shown in Fig. 4, the propagation path losses can be measured utilizing calibrated RCS reflectors at the desired range. The propagation loss during adverse weather conditions can be determined from the received signals from the calibrated reflectors, and compared to that obtained during clear-air conditions. This requires the utilization of a highly stable radar, or a radar that can be independently calibrated for output power as well as for transmitter and receiver losses. It is also required that the calibrated reflectors be kept clear of rain and snow, as well as that of the radar antenna.

Microwave and millimeter-wave transmissometers can determine the one-way propagation path loss. The configuration of the transmissometer is shown in Fig. 6. Transmissometers generally utilize a low-power RF source at the transmitter site coupled to the RF antenna. The power output of the transmitter source needs to be measured continuously by the power meter, and the measured power output would be transmitted to the system computer through an RS-232 or similar link. At the receive end, identical sized antennas would couple the RF signal through a precision attenuator to the mixer preamplification for downconversion to the intermediate frequency (IF) frequency of the logarithmic amplifier (Log Amp) and video detector. Since the transmitter source is non-coherent and subject to possible drift in frequency, either the receiver bandwidth must be sufficient to accommodate any frequency drift, or the receiver must be tuned to the frequency of the transmitter source. The simplest configuration would be to use a narrowband receiver, and slowly sweep the receiver frequency over the range of expected transmitter frequency variations. The computer samples the receive signal amplitude to determine the frequency of the peak return amplitude. By utilizing the precision attenuator in the receiver and the power meter output, an accurate determination can be made of the propagation attenuation between that of the clear air path and that due to adverse weather conditions.

D. Meteorological Instrumentation

MMW propagation under adverse weather conditions is certainly affected by the meteorological conditions present during the testing, and therefore precise knowledge of the actual meteorological conditions during the testing is vital to provide quantifiable results. Listed in Table I are a number of standard meteorological sensors that are being installed for adverse weather testing at the PAL. Standard meteorological instrumentation includes wind speed, wind direction, temperature, humidity, and barometric sensors.

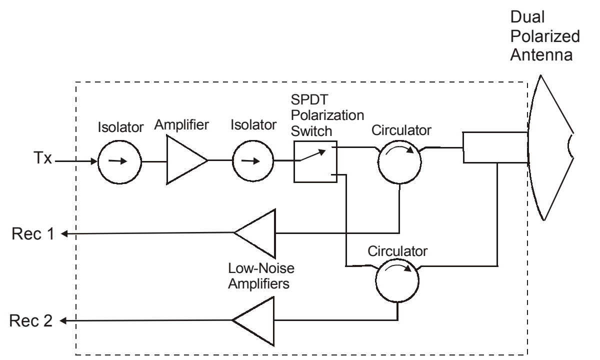

Fig. 5. Dual-polarized RF Head

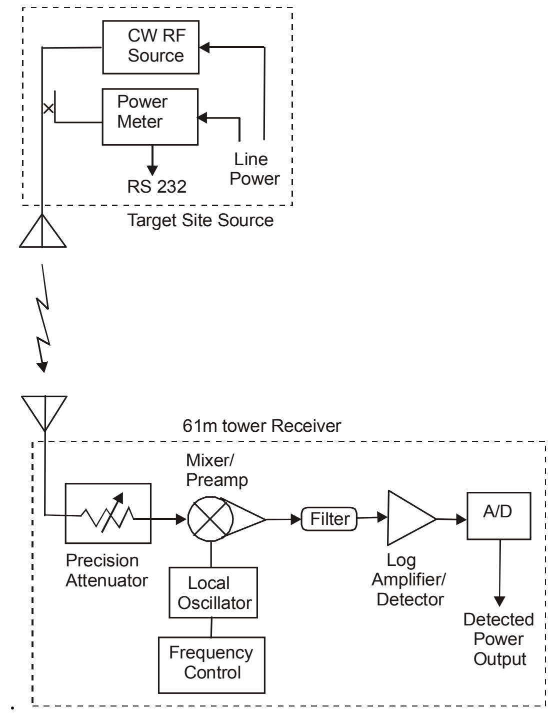

Fig. 6. RF transmissometer.

TABLE I

METEOROLOGICAL INSTRUMENTATION TYPES

Sensor	*Measures*	*Comments*
Anemometer	Wind speed	
Wind Vane	Wind direction	
Thermometer	Temperature	
Humidity Sensor	Humidity	
Barometer	Barometric pressure	
Snow/Rain Tipping Bucket	Rain rate	Also melted snow liquid rate
Optical Rain Gauge	Rain rate	Possibly snow rate
Visibility Meter	Visibility	Smoke, fog, haze
Pyranometer	Sun and sky radiation	
Pryheliometer	Solar radiation direction	Required tracking mount
Distrometer(s)	Drop sizing	Haze, fog, mist, drizzle, rain
Snow Depth Gauge	Snow depth	
Soil Block	Soil moisture	

Recording of wind speed and direction is vital since it can affect the shape of the raindrops and snow crystals and their orientation to the radar. The Doppler obtained from precipitation returns can affect the performance of clutter rejection techniques such as moving target indication (MTI) or Doppler processing. The size of the raindrops or snow crystals can affect the propagation returns since in most cases their size is in the Rayleigh scattering region where the reflectivity falls off as the fourth power of the drop size. Humidity and temperature are an indication of the moisture in the air that affects the propagation attenuation.

Other standard instrumentation includes rain gauges, a tipping bucket type and an optical rain gauge. Heated tipping bucket rain/snow gauges provide for measurement of the liquid water content of the snow, as well as that for rain. Temperature and humidity sensors are readily available as standard meteorological sensors, but must be mounted in a radiation shield to prevent the solar radiation from affecting the temperature readings. Collection of meteorological data will be provided by connecting the meteorological instrumentation to a data logger. The data logger provides for automated data collection and can network the data to a central recording facility. Automated weather stations, including data loggers and meteorological instrumentation, are available from a number of manufacturers.

Advanced meteorological sensors that will be available at the PAL include an optical rain gauge, distrometers, snow depth gauge, and soil temperature and moisture blocks. Optical rain gauges have the capability of performing more precise measurements at low rain rates, and at extremely high rain rates. Distrometers provide measurement of precipitation sizes, and associated signal processing can provide histograms of the precipitation drop size distributions. Three different distrometers are required to determine the whole range of drop size distribution covering haze, fog, mist, drizzle and rain. Solar radiation can potentially affect the performance of the MMW radars due to thermal effect or possible inversion layer effects. Pyranometers measure total sun and sky radiation. If the direction of the solar radiation is an important factor, then use of a normal incidence pryheliometer along with a solar tracking mount will provide the required information.

Placement of the meteorological sensors is important. The wind speed and direction can differ substantially between ground level and nominal propagation path heights. The World Meteorological Organization (WMO) (1) defines the standard height for anemometers and wind direction sensors to be 10 m above ground level. The placement of the meteorological instrumentation is also a factor in obtaining reliable weather data. The WMO recommends setting the instrumentation in open terrain "where the distance between the anemometer is at least 10 times the height of the obstruction." In addition to measuring the wind speed and velocity at ambient, it may also be desired to measure it at the level of the target and at the radar locations. It is also important to shield the exposure of the rain gauge from wind effects and from splashing, and recommendations on placement of rain gauges is provided in Middleton (2). Table II provides recommendations for placement meteorological instrumentation. Fig. 3 shows a tower configuration for mounting the basic meteorological sensors at the target site. It also includes lightning protection and collision avoidance lights. A fold-over or retractable tower would facilitate servicing of the anemometer as well as the collision avoidance lights.

III. SUMMARY

Automated measurement of clutter and propagation under adverse weather conditions is the best way to insure collection of data when the desired weather conditions occur. A vast array of meteorological instrumentation being installed at the PAL will provide quantification of the actual weather conditions at the time of the measurement. Precipitation rates tend to vary markedly from site to site, so that utilization of the weather data from a remote site is likely to provide erroneous information. Careful attention has been paid to the implementation and placement of the weather instrumentation so that it does not interfere with the radar sensor returns, but yet still provides accurate information on the weather conditions in the target area, at the radar site, and along the propagation path. Characterization of the clutter and the propagation path are important to radar performance testing. RCS and propagation measurement equipment, in addition to the meteorological instrumentation, are planned for installation at the PAL. The US Army is specifically

addressing such adverse weather measurements in order to develop and qualify sensor performance for precision munition systems by constructing the Precision Armaments Laboratory.

TABLE II.

CONSIDERATIONS FOR PLACEMENT OF METEOROLOGICAL SENSORS (3)

Sensor Type	*Measurement Height or Depth*	*Exposure Considerations*
Wind	3 m ± 0.1 m recommended (AASC (4)); 2 m ± 0.1 m, 10 m ± 0.5 m, optional (AASC); 10 m (WMO[1] & EPA (5))	No closer than ten times the obstruction's height
Air Temperature and Relative Humidity	1.5 m ± 1 m (AASC); 1.25-2.0 m (WMO); 2.0 m for temperature only (EPA); 2 m & 10 m for temperature difference (EPA)	The sensor must be housed in a ventilated radiation shield to protect the sensor from thermal radiation. The EPA recommends the sensor be no closer than four times the obstruction's height and at least 30 m from large paved areas.
Solar Radiation	Height should be consistent with the exposure standard (AASC, WMO, EPA). To facilitate leveling/cleaning, CSI (6) recommends installing at a height of 3 m or less.	The sky should not be blocked by any surrounding object. However, objects <10° above the horizontal plane of the sensor are allowed.
Precipitation	1.0 m ± 0.2 m (AASC); 30 cm minimum (WMO)	AASC & EPA suggest the sensor be no closer than four times the obstruction's height. The orifice of the gauge must be in a horizontal plane, open to the sky, and above the level of in-splashing and snow accumulation.
Soil Temperature	10 cm ± 1.0 cm (AASC); 5 cm, 10 cm, 20 cm, 50 cm, 100 cm (WMO)	Measurement site should be 1 m² and typical of the surface of interest. The ground surface should be level with respect to the immediate (10 m radius) area.

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[3] From: http:/www.campbellsci.com/siting.html

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[6] Campbell Scientific, Inc.